Supplementary Material:

Accessing real-life episodic information from minutes versus hours earlier modulates hippocampal and high-order cortical dynamics

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Supplementary Methods and Results

Supplementary Figure S1 (Related to Figure 3): Number of reliable voxels in Timescale ROIs during each 2-minute time window of Part 2 of the movie.

Supplementary Figure S2 (Related to Figure 3): Replication of within-group inter-subject correlation maps across the two independent Recent Memory groups.

Supplementary Figure S3 (Related to Figure 4): Volume view of inter-subject correlation maps showing reliable voxels in hippocampus for all conditions (full 10-minute duration of Part 2).

Supplementary Figure S4 (Related to Figure 5): Hippocampus inter-subject functional correlation maps, plotted at a lower statistical threshold than in Figure 5.

Supplementary Figure S5 (Related to Figure 6): Replication of Distant vs. Recent Memory timecourse correlations in Timescale ROIs, across the two indpedent Recent Memory groups.

Supplementary Figure S6 (Related to Figure 6): Distant vs. Recent Memory timecourse correlations in Timescale ROIs, shown at multiple window sizes.

Supplementary Figure S7 (Related to Figures 4 and 6): Early hippocampal-cortical coupling predicts later cortical activity in Distant Memory condition.

Supplementary Table S1 (Related to Figure 1): Post-scan memory test questions.

Supplementary Table S2 (Related to Figure 1): Examples of questions from the Stop-and-ask memory test.

Supplementary Methods and Results

Timescale Localizer

Methods

The audiovisual movie used for the localizer was a 325 second clip from the 1975 commercial film *Dog Day Afternoon* (Lumet 1975). The full movie clip served as the stimulus for the "Intact" condition of the localizer. For the "Coarse Scramble" condition, the movie clip was segmented into 24 sections of 7.1-22.3 seconds; the sections were temporally permuted and then concatenated to create a new 325 second movie. The 24 sections were further subdivided to produce 334 sections of 0.5-1.6 seconds and concatenated to create the "Fine Scramble" movie. These stimuli were the same as described in (Honey et al. 2012). Twelve volunteers, all native English speakers with normal or corrected-to-normal vision, participated. Each subject viewed all three conditions, twice for each condition, with the expection of one subject who did not have a Coarse Scramble condition. The order of conditions was counterbalanced.

MRI data acquisition and preprocessing were the same as described for the main experiment. ISC maps were produced for each experimental condition (Fine Scramble, Coarse Scramble, and Intact; see *Methods: Inter-subject correlation*) and thresholded at $R^* = 0.2$. Timescale ROIs were then created using the following algorithm: a voxel was identified as "short timescale" if it was present in all three maps (i.e., it responded reliably in all three conditions); a voxel was identified as "medium timescale" if it was present in the Coarse Scramble and Intact maps but not in the Fine Scramble map; and a voxel was identified as "long timescale" if it was present in the Intact map but not in the other two maps. These assignments were used to create the long-timescale (4954 voxels), medium-timescale (7030 voxels), and short-timescale (8628 voxels) ROIs. For more details about timescale mapping ("temporal receptive window" mapping) see: (Hasson et al. 2008; Lerner et al. 2011; Honey et al. 2012).

Early hippocampal-cortical coupling in Distant Memory subjects is associated with later cortical reliability in long-timescale areas

Methods

Control analyses were conducted 1) using a short-timescale ROI (auditory cortex) in place of the long-timescale ROI; 2) using the other Recent Memory group in place of Distant Memory; 3) using No Memory in place of Distant Memory. In (3), we compared the correlation magnitude when using No Memory in place of Distant Memory to that derived from the original analysis (early Distant Memory hippocampal-cortical coupling vs. later cortical similarity to Recent Memory) using a non-parametric bootstrapping procedure. For each group we generated 1000 bootstrap samples by each time selecting with replacement a different subset of *n* individuals from our pool of *n* subjects. For each sample, we calculated the correlation between the predictor and predicted variables. The upper limit (ul) for an x% confidence interval was the Pearson correlation in percentile x of the bootstrap distribution; the lower limit (ll) for the confidence interval was set to correlation value in percentile 100-x of the distribution. Using the following formulae proposed by (Zou 2007) for application to two bootstrapped correlation confidence intervals, we computed r_{diff}, upper confidence limits (ul_{diff}), and lower confidence limits (ll_{diff}) for the difference between two correlations:

$$r_{diff} = r_1 - r_2$$
$$ll_{diff} = r_1 - r_2 - \sqrt{(r_1 - ll_1)^2 + (ul_2 - r_2)^2}$$
$$ul_{diff} = r_1 - r_2 + \sqrt{(ul_1 - r_1)^2 + (r_2 - ll_2)^2}$$

Confidence intervals that did not encompass zero were considered reliable at the given level of confidence.

Results

In this analysis, we examined individual differences in how *hippocampal-cortical interaction early in Part 2* related to *cortical timecourses later in Part 2*. A significant correlation was observed between 1) hippocampal-cortical interaction (ISFC) early in the movie, and 2) the level of cortical similarity between Distant Memory subjects and the

Recent Memory groups later in the movie (RM1, R = 0.63, p < 0.05; RM2, R = 0.60, p < 0.05; Figure S7; see Methods). Given our prior finding that Distant Memory and Recent Memory long-timescale cortical timecourses were statistically different for up to four minutes (3 minutes q < 0.05, 4 minutes q < 0.1; Figure 6), we used Minutes 1-4 as the "early" window, and the remainder of Part 2 (Minutes 6-10) as the "late" window. No significant correlations were observed in control analyses: 1) using a short-timescale ROI (auditory cortex) in place of the long-timescale ROI (R = 0.38, p > 0.1); 2) using the other Recent Memory group in place of Distant Memory (RM1-early vs. RM2-late, R = 0.32, p > 0.3; RM2-early vs. RM1-late, R = 0.34, p > 0.2); or 3) using No Memory in place of Distant Memory (R = -0.44, p > 0.1). The correlation of early Distant Memory hippocampal-cortical coupling with later cortical similarity to Recent Memory was significantly higher than when No Memory was used in place of Distant Memory (r_{diff} = 1.07, 2-way, p < 0.05, 95% ll_{diff} = 0.38, ul_{diff} = 1.42).

Figure S1, Related to Figure 3

Number of Reliable Voxels Over Time
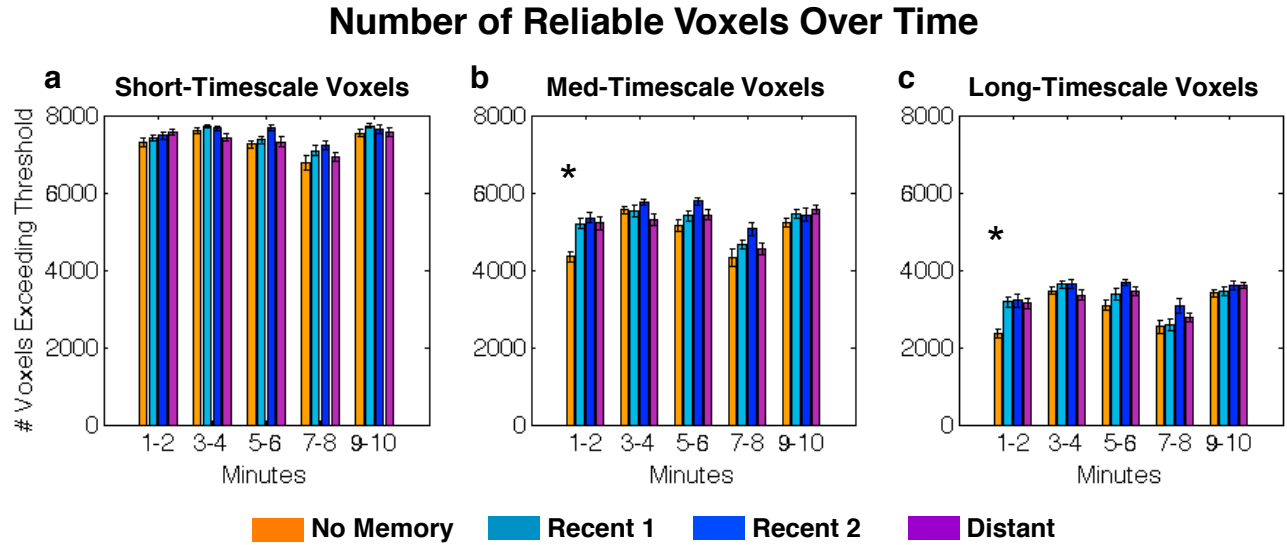
Figure S1. The number of voxels where R > 0.1 in each condition in each ROI in each 2-minute time window over the duration of Part 2. **a)** Short-timescale ROI: main effect of Time (five 2-minute windows), $F_{(4,188)}$ = 33.45, $p < 0.0001$; no significant effect of Group or Interaction. ROI is 8628 voxels. **b)** Medium-timescale ROI: main effect of Time (five 2-minute windows), $F_{(4,188)}$ = 39.01, $p < 0.0001$; of Group, $F_{(3,47)}$ = 5.87, $p < 0.005$; Group x Time interaction, $F_{(12,188)}$ = 2.88, $p < 0.005$. Significant effect of Group, 1-2 minute window $F_{(3,47)}$ = 9.44, $p < 0.0001$; other windows n.s. after multiple comparisons correction for 5 windows, pcrit = 0.01. Two-tailed t-tests of No Memory vs. other groups, $p < 0.005$ in 1-2 minute window. ROI is 7030 voxels. **c)** Long-timescale ROI: main effect of Time (five 2-minute windows), $F_{(4,188)}$ = 44.94, $p < 0.0001$; of Group, $F_{(3,47)}$ = 6.55, $p < 0.0008$; Group x Time interaction, $F_{(12,188)}$ = 2.60, $p < 0.005$. Significant effect of Group, 1-2 minute window $F_{(3,47)}$ = 9.83; other windows n.s. after multiple comparisons correction for 5 windows, pcrit = 0.01. Two-tailed t-tests of No Memory vs. other groups, $p < 0.005$ in 1-2 minute window. ROI is 4954 voxels.

Figure S2, Related to Figure 3

Within-Group Inter-Subject Correlation: Replication Across Two Independent Groups

a   Recent Memory 1   **b**   Recent Memory 2

0.1   R   0.5
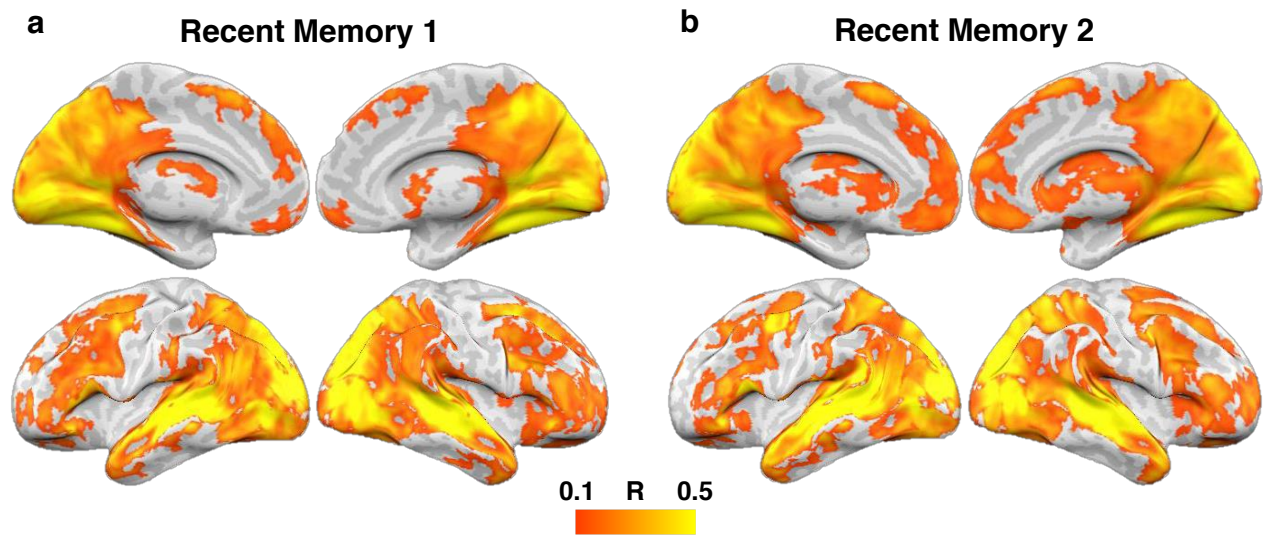
Figure S2. Replication of inter-subject correlation (ISC) maps across two independent groups of subjects randomly selected from the same experimental condition, *Recent Memory 1* (*RM1*, N = 12) and *Recent Memory 2* (*RM2*, N = 12), during Minutes 1-2 of Part 2 of the movie. ISC is calculated by first finding the correlation between each subject's timecourse and the average of all others in the group at every voxel, then averaging across all subjects in the group to create a single summary map. **a)** ISC map for *RM1*. **b)** ISC map for *RM2*.

Figure S3, Related to Figure 4

ISC during Minutes 1-10 of Part 2
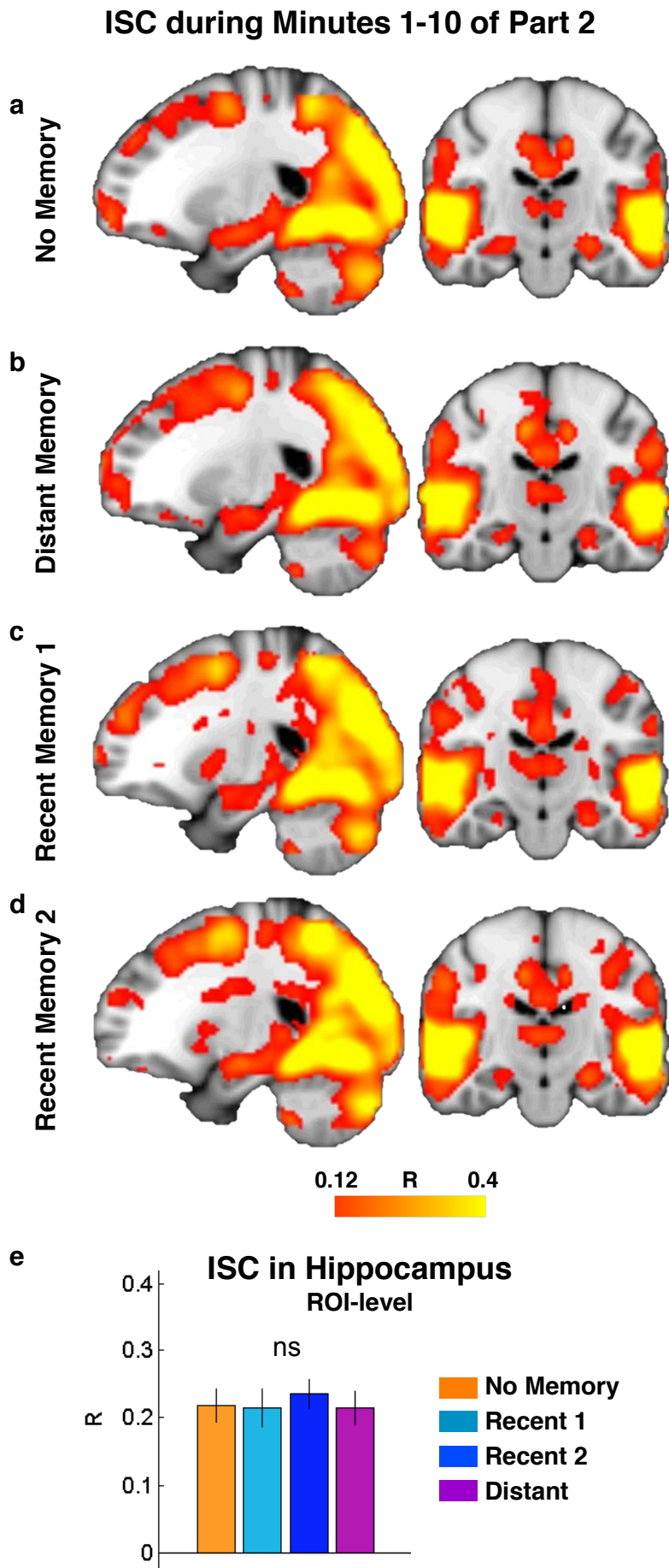
Figure S3. Voxels throughout the hippocampus were reliable in all groups when ISC was calculated across the full 10 minutes of Part 2 of the movie. The brain-wide bootstrapped statistical threshold was between 0.060 and 0.065 for all groups (see Methods); maps are thresholded at 0.12 for display purposes. Error bars show standard error of subjects. **a)** ISC map for the *No Memory* group. **b)** ISC map for the *Distant Memory* group. **c)** ISC map for the *Recent Memory 1* group. **d)** ISC map for the *Recent Memory 2* group. **e)** ROI-level ISC in the hippocampus calculated across the full 10 minutes of Part 2. No significant differences were found between groups (F(3,47) = 0.16, p > 0.9).
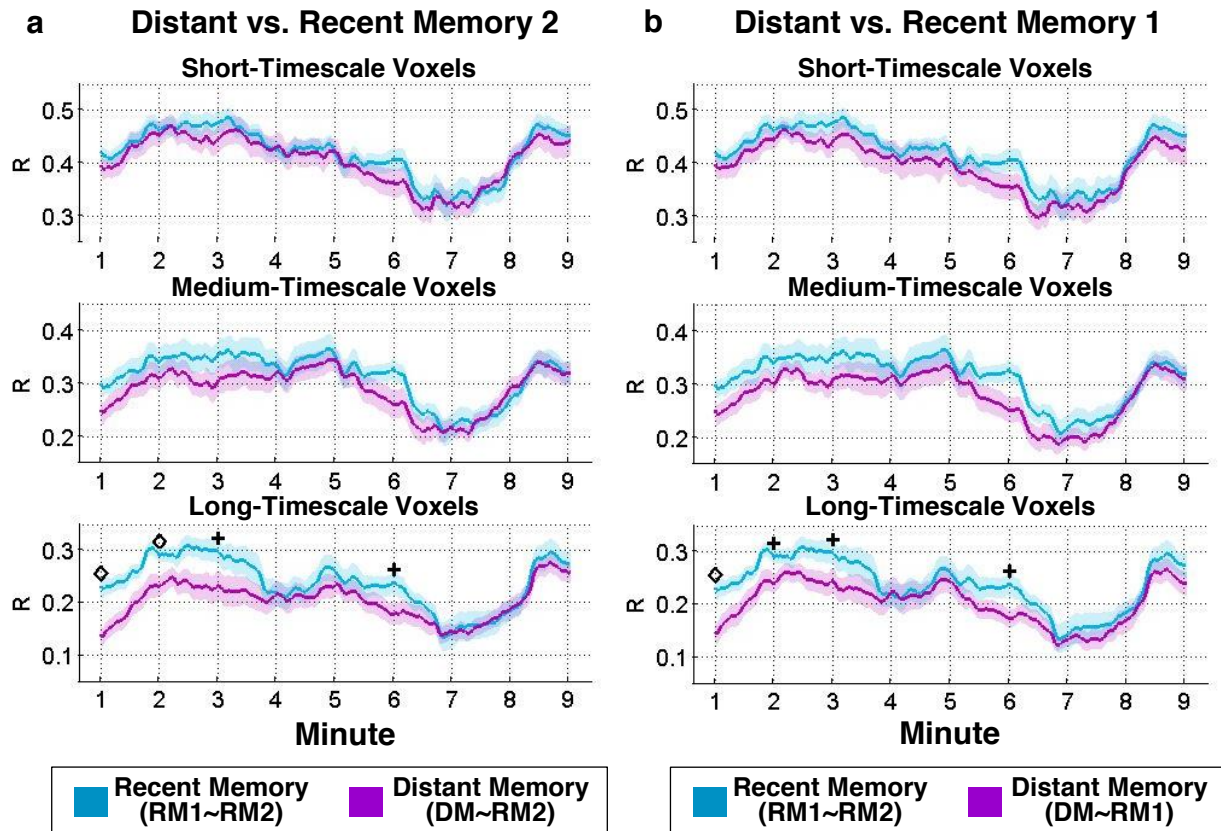
Figure S4, Related to Figure 5

Hippocampus Activity Correlates with Long-Timescale Cortical Regions

Recent Memory	Distant Memory	No Memory

0.15   R   0.3
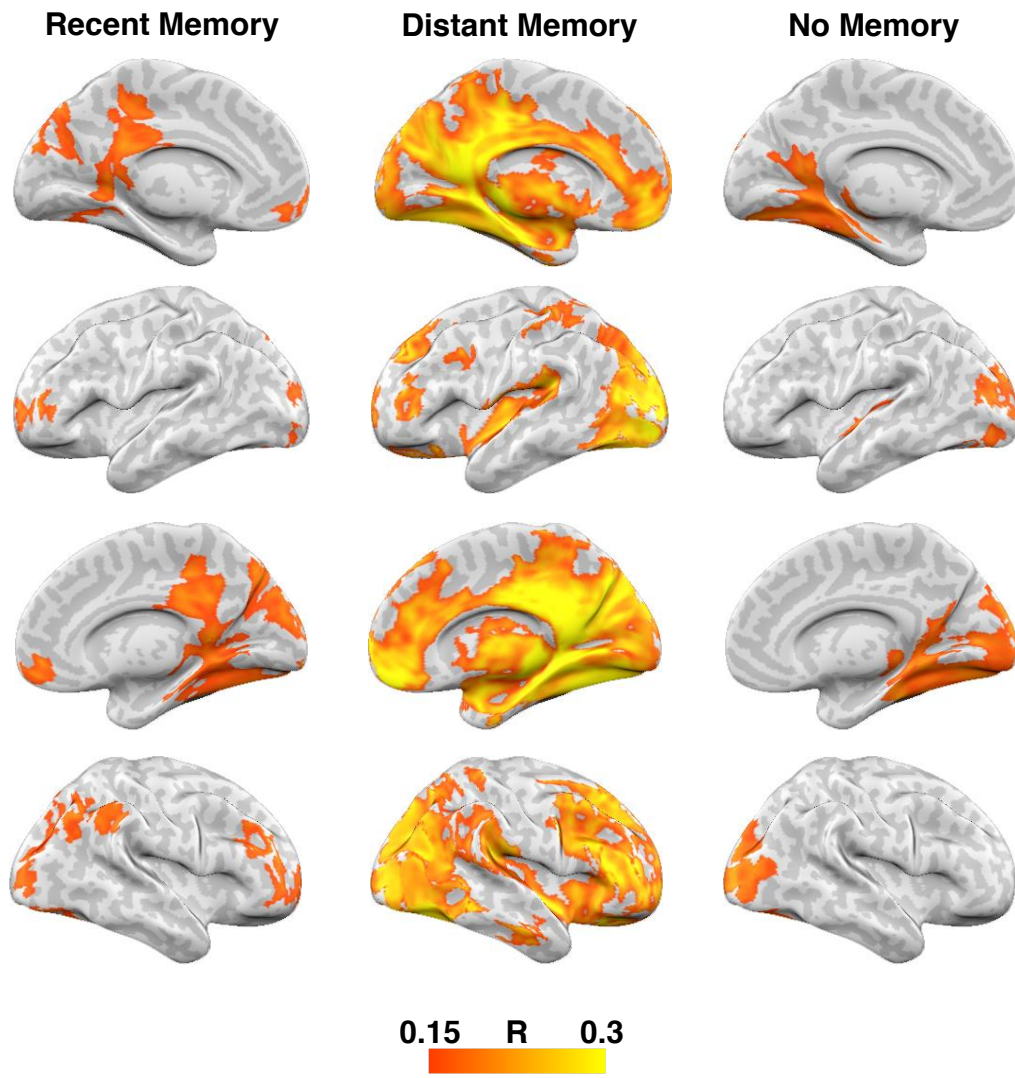
Figure S4. Stimulus-locked correlations between hippocampus and the rest of the brain during Minutes 1-2 of Part 2. Same data as Figure 5a, plotted at a lower threshold (not corrected for multiple comparisons) in order to show correlations in *Recent Memory* and *No Memory* that were qualitatively similar to *Distant Memory* but did not reach statistical significance.
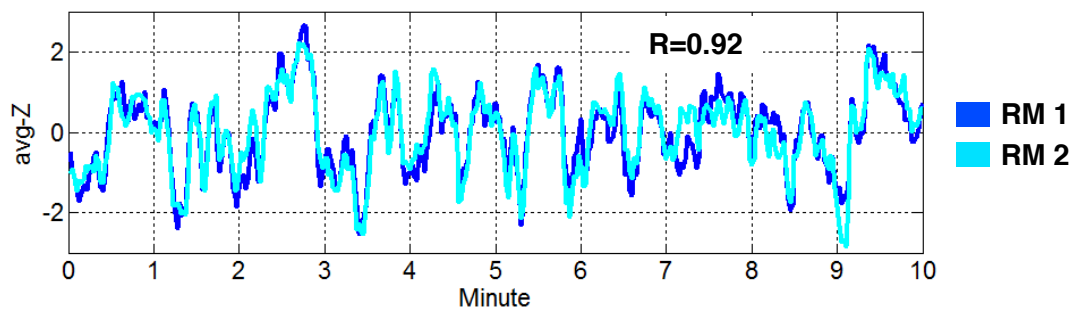
Figure S5, Related to Figure 6

Consequences of a 1-Day Break:
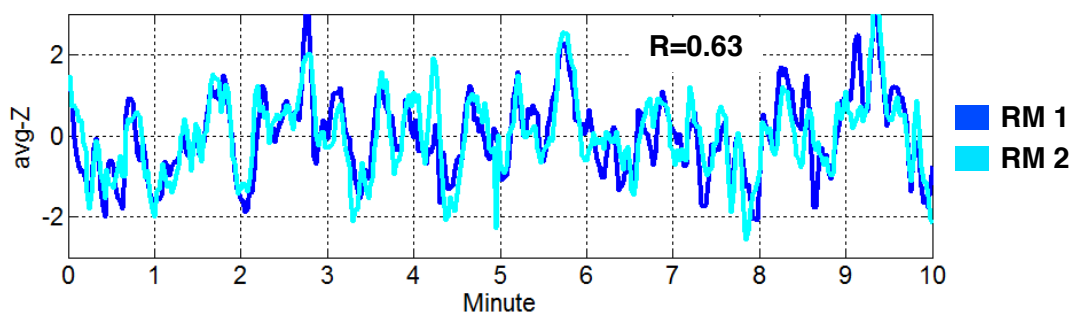**Replication Across Two Independent Groups**

a **Distant vs. Recent Memory 2**

Short-Timescale Voxels

Medium-Timescale Voxels

Long-Timescale Voxels

Minute

Recent Memory (RM1~RM2) | Distant Memory (DM~RM2)

b **Distant vs. Recent Memory 1**

Short-Timescale Voxels

Medium-Timescale Voxels

Long-Timescale Voxels

Minute

Recent Memory (RM1~RM2) | Distant Memory (DM~RM1)

c **RM1 and RM2 Mean Timecourses in a Short-Timescale Region**

Mean Timecourses: Auditory Cortex

R=0.92

RM 1
RM 2

d **RM1 and RM2 Mean Timecourses in a Long-Timescale Region**

Mean Timecourses: PCC

R=0.63

RM 1
RM 2

Figure S5. Replication of results from Figure 6 across the two independent *Recent Memory* groups. **a)** At every voxel in each region we calculated the correlation between activity in *Distant Memory* and *Recent Memory* (*DM~RM2*, purple) using a sliding window across the duration of Part 2, then averaged within-region to create the plotted timecourses. To estimate the maximum possible similarity between groups at every time window, we calculated the correlation between two independent groups in the *Recent Memory* condition (*RM1~RM2*, blue) using the same procedure. The gap between *DM~RM2* and *RM1~RM2* indicates differing neural dynamics when subjects had a one-day break (*Distant Memory*) versus no break (*Recent Memory*) between Part 1 and Part 2 of the movie. *Distant Memory* and *Recent Memory* were most dissimilar at the beginning of Part 2, and became gradually more aligned over time. Neural effects of the 1-day break lasted until the window ending at 3 minutes in long-timescale voxels. The sliding window was 120 s wide and center-plotted, i.e., the first value in the trace corresponds to time window 0-120 s. Diamonds indicate q < 0.05, crosses indicate q < 0.1, FDR corrected. **b)** Same analysis as in (a) but with *RM1* and *RM2* reversed. **c)** Mean timecourses from a short-timescale region, auditory cortex, in the two independent *Recent Memory* groups, across the entire duration of Part 2 of the movie. Correlation between the two timecourses was R = 0.92. **d)** Mean timecourses from a long-timescale region, posterior cingulate cortex, in the two independent *Recent Memory* groups, across the entire duration of Part 2 of the movie. Correlation between the two timecourses was R = 0.63.

Figure S6, Related to Figure 6

Distant vs. Recent Memory Correlation Timecourses with a Range of Window Sizes
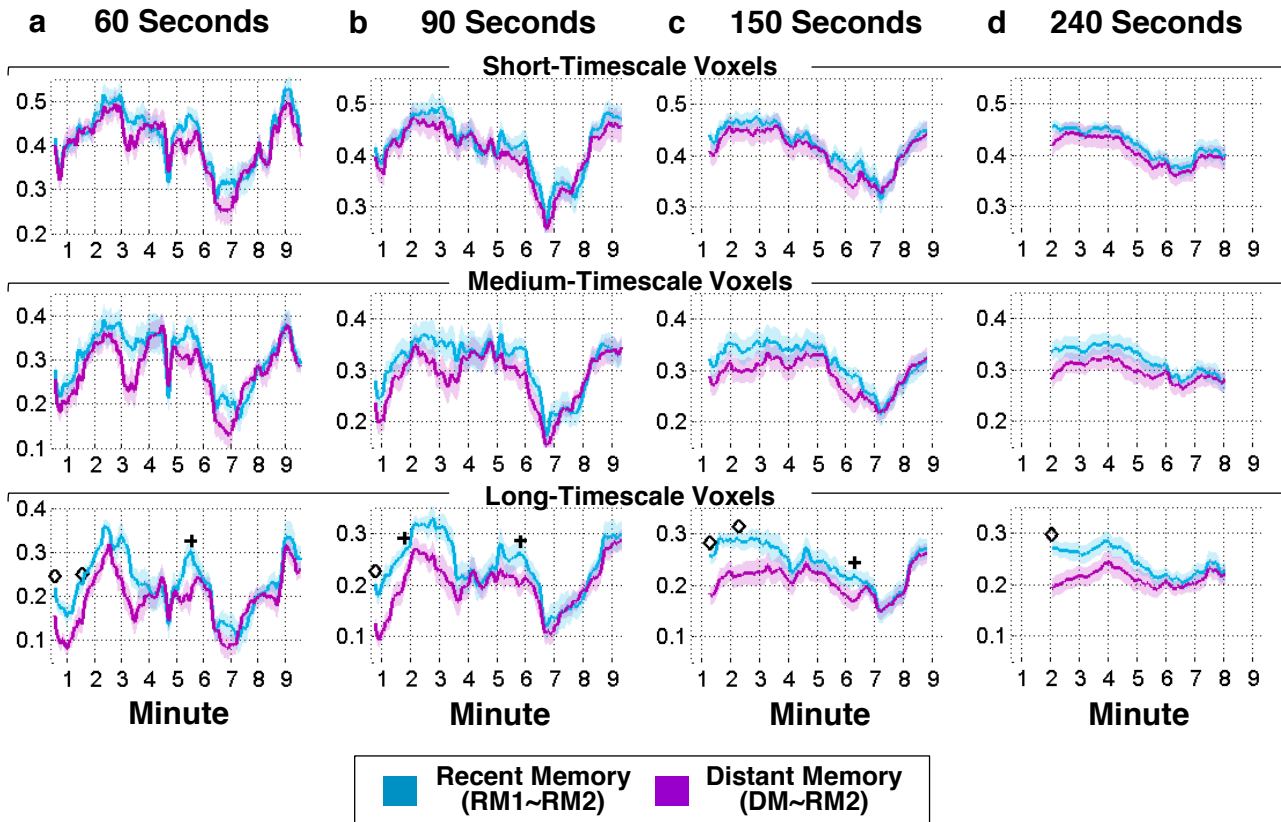
Figure S6. Between-group similarity of neural responses during Part 2. **(a-d)** Within each Timescale ROI we calculated the correlation between activity in *Recent Memory* and *Distant Memory* (*DM~RM2*, purple) using a sliding window across the duration of Part 2. To estimate the maximum possible similarity at any given time window, we plotted the correlation between two independent groups in the *Recent Memory* condition (*RM1~RM2*, blue). These calculations were performed at every voxel and then averaged within ROIs. Diamonds indicate q < 0.05, crosses indicate q < 0.1, FDR corrected for one test per minute starting at the first timepoint. As tests are performed at the window size indicated, the last timepoint contributing to a given significance marker is the plotted timepoint plus half the window size. For example, in (d), the significant window (marked with a diamond) extends to 240 s. Correlation timecourses calculated with a sliding window size of 120 seconds are used throughout the paper and depicted in Figure 3. **(a)** Correlation timecourses calculated with a sliding window size of 60 seconds. **(b)** Correlation timecourses calculated with a sliding window size of 90 seconds. **(c)** Correlation timecourses calculated with a sliding window size of 150 seconds. **(d)** Correlation timecourses calculated with a sliding window size of 240 seconds.

Figure S7, Related to Figure 4

Early Hippocampal-Cortical Coupling Predicts Later Cortical Activity in Distant Memory Group
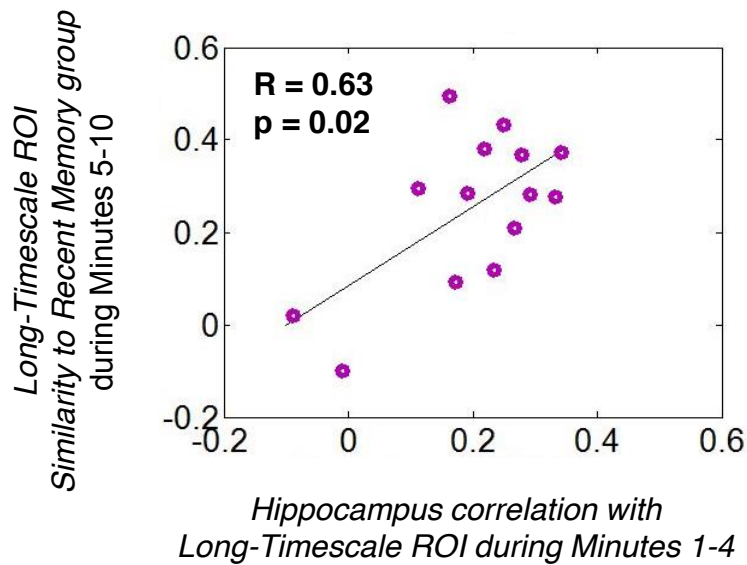
Figure S7. During Part 2 of the movie, early hippocampal-cortical coupling in *Distant Memory* subjects predicted later cortical similarity to *Recent Memory* subjects. For each subject in the *Distant Memory* group, we calculated ISFC between the hippocampus and the long-timescale ROI during the beginning of Part 2 (Minutes 1-4). Next, we calculated the similarity of each subject's long-timescale ROI timecourses, during the remainder of Part 2 (Minutes 5-10), to the average *Recent Memory (RM1)* long-timescale ROI timecourse. A significant correlation was observed (R = 0.63, p = 0.02).

Supplemental Tables

Table S1. Post-Scan Memory Test Questions, Related to Figure 1

Time-Specific Questions: Part 1 of Movie
1. What kind of flowers was the daughter holding in the photograph at the beginning of the movie?
2. What temperature did the father call "the optimum temperature"?
3. Who did the daughter push down the stairs?
4. What did the butler bring to the father?
5. What kind of book was the daughter looking in at the beginning of the movie?
6. What were the ceilings designed to have?
7. What happened to the person who was pushed down the stairs?
8. What time was dinner?
9. How did the daughter describe the family house? "Everything designed for ___"
10. What did the daughter threaten to do if her father did not agree to her request regarding the servants?
11. What did the daughter drop on the floor and break?
12. Fill in the blank: The daughter called the servants "walking ___"

Behavioral Performance on Part 1 Questions (1-3 scale, where 1=incorrect):
    Recent Memory, mean 2.44, s.d. 0.22
    Distant Memory, mean 2.30, s.d. 0.16
    No Memory, mean 1.08, s.d. 0.13

Time-Specific Questions: Part 2 of Movie
13. What was on top of the dresser in the daughter's room?
14. What was the daughter doing in her room when her father came looking for her?
15. What did the father agree to do "right away"?
16. After her father agreed to her demand, the daughter said "All of you, ___".
17. How did the father summon the servants?
18. Where did the father order the butler to take the servants?
19. What did the butler do when the the father ordered him to take the servants away?
20. What was the mother doing when the father told her that "we're alone in the house now"?
21. What holidays did the mother point out pictures of in the photo album?
22. After her father completed her request, the daughter said to her mother, "We're going to live like ___".
23. What did the daughter say that made her mother upset because the mother knew it was impossible?
24. How did the daughter figure out that she was a robot?
25. What did the daughter say just before she started crying on the stairs?

Behavioral Performance on Part 2 Questions (1-3 scale, where 1=incorrect):
    Recent Memory, mean 2.34, s.d. 0.17
    Distant Memory, mean 2.36, s.d. 0.20
    No Memory, mean 2.26, s.d. 0.25

General Questions
26. What was the name of the maid who gave the mother massages?
27. Why was the daughter upset about the servants?
28. What was the butler's name?
29. What was the father's name?
30. What was the daughter's name?
31. At what point did you realize that the daughter was a robot, and why? Please be as specific as possible. If you suspected it at one point in the movie and were not sure until another point, please describe both.

Table S2. Examples of Stop-and-Ask Questions for Movie Part 2, Related to Figure 1

What is the man going to say next? (27.0 s) 1. Karen, dear... 2. Jana, dear... 3. Alice, dear... 4. Moira, dear...	What is the man going to say next? (66.0 s) 1. Then you will stay? 2. Then you willl come with us? 3. Then you will forget about him? 4. Then you will bring them here instead?
What is the man going to say next? (29.4 s) 1. You don't really want to leave us, do you? 2. Why are you so angry with me? 3. Are you ready to go? 4. I've missed you so much.	What is Jana going to say next? (72.0 s) 1. What about her? 2. No. 3. You don't know what you want. 4. It just isn't safe.
What is Jana going to say next? (35.2 s) 1. No... I'm going to miss this place, my love. 2. Don't pretend that you care, Mr. Fowler. 3. Well, you ordered me to go, Charles. 4. I thought I made it quite plain, Father.	What is the man going to say next? (85.0 s) 1. Jana, I wonder what Harold will think. 2. Jana, you know what's out there. 3. Jana, you'll never find your way out of this place. 4. Jana, I'll do what you asked me to do.
What is Jana going to say next? (42.4 s) 1. I never get to see you anymore. 2. It's much too warm in here. 3. I want you to let the world in. 4. I'm not afraid of what people will think.	What is Jana going to say next? (97.0 s) 1. Nelda, Gretchen, Suzanne, all of you -- rest in peace. 2. Mother will be so pleased. 3. I can't wait to see the look on James's face. 4. He's as foolish as the rest of them.
What is the man going to say next? (45.4 s) 1. By destroying my whole life's work? 2. He's gone for good, you know that. 3. Why do want to go back out there? 4. But what will your sister think?	Who is on the screen right now? (115.0 s) (catch trial) 1. The man 2. Nelda 3. Jana 4. Nobody
What is the man going to say next? (48.8 s) 1. Jana, you'll never be able to find them. 2. Jana, we've loved you very much. 3. Jana, you take their criticism too seriously. 4. Jana, it's who I am - I can't give it up.	What is the man going to say next? (138.6 s) 1. George. 2. Mr. Fowler. 3. Robert. 4. Dr. Loren.
What is the man going to say next? (52.2 s) 1. all of this has been just as much for you as for ourselves.	What is the man going to say next? (140.0 s)

2. there's nothing left for any of us here. 3. he isn't what you thought, and he isn't coming back. 4. we don't know, any of us, if it's safe here. What is Jana going to say next? (61.8 s) 1. I just don't know whether to believe you. 2. And he never did. I know that. 3. It doesn't matter to me at all. 4. I know that, Father. I know that.	1. Jana wants you to see you upstairs. 2. I want you to take all the servants downstairs. 3. The master is waiting for your answer. 4. Mother has made a decision. What is Robert going to say next? (147.4 s) 1. Have our services been unsatisfactory, sir? 2. Did Mother ask you to do this? 3. Will Jana come with us? 4. Will you take us with you when you go?